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DATA AVAILABILITY

Regional normalisation figures for Australia 2005/2006—inventory and characterisation data from a production perspective

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Abstract

Background, aim, and scope Under ISO 14040, normalisation is an optional step in life-cycle impact assessment designed to provide environmental context by indicating the relative contribution that the product system under investigation makes in the various impact categories, in comparison to a suitable reference scenario. The challenge for many studies, however, is to provide the appropriate context by adopting a normalisation reference scenario that is well matched to the product system's parent environment. Australia has a highly urbanised population, mainly contained in just eight capital cities. In the context of normalising environmental impacts against the profile of an 'average' Australian, this poses a unique problem, compared to other industrialised regions of the world. This study aims to use publicly available data on environmentally relevant emissions and non-renewable resource consumption in 2005/2006 to develop regional normalisation data for Australia, at both inventory and characterisation levels.

Methods The regionalised inventory of emissions and resources production is constructed using a framework of 60 regional Statistical Divisions from the Australian Standard Geographical Classification system. Data from the National Pollutant Inventory, Australian Greenhouse Emissions Information System and the Australian Bureau of Agricultural and Resource Economics (energy and mineral statistics) are used as the basis for the inventories. These data could subsequently be used by any LCA practitioner to construct characterisation or normalisation data by impact category, according to any preferred life-cycle impact assessment methodology, for any of 60 regions in the country. In this study, the regionalised inventory data were assessed using the CML 2001 baseline and IMPACT 2002+ life-cycle impact assessment methods in SimaPro v.7.1.5.

Results Characterisation results from the two LCIA methods for Australia's eight state and territory capital cities are presented, together with an overall national profile. These data are also shown on a per capita basis to highlight the relative environmental profiles of citizens in the different cities. Interestingly, many significant impacts occur outside of the capital cities but are linked to facilities providing the majority of their services and products to these urban centres (e.g. power stations, minerals processing). Comparison of the average Australian data with the Netherlands, Western Europe and the World shows the results to be broadly similar.

Discussion Analysis of the CML 2001 baseline characterisation results, on a per capita basis, shows substantial differences between the major cities of the country. In each impact category, these differences can be successfully traced to specific emissions in the raw data sources, the influence of prevailing climate conditions, or factors such as the mix of non-renewable energy resources in each state. Some weaknesses are also evident in the collection and estimation techniques of the raw data sources and in the application of European-based impact assessment models.

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Australia is a net exporter of many products, particularly natural resources. Therefore, a significant part of the characterisation data presented here for Australia represents products that will be consumed in other parts of the world. Similarly, at a regional level, there will be many inventory items produced in one area yet consumed in another. In this way, the impacts associated with consumption (particularly in densely populated but largely industry-free cities) are dissipated into other production centres.

Conclusions This study provides the first set of comprehensive inventory and characterisation data for Australia from a production perspective, disaggregated at a regional level. Despite Australia's unique spatial demography, it is now possible to properly characterise the relative significance of environmental impacts occurring in any of 60 specific regions across the country.

Recommendations and perspectives Australia's unique concentration of urban populations demonstrates the importance of regionally specific environmental assessments. Whilst the data presented in this study will be of most use to Australian LCA practitioners, it is also demonstrative of the broader global distribution of environmental impacts between urban and non-urban areas. The disconnection of environmental impacts between the place of production and the place of consumption is highlighted by this study and should be considered in any studies using these normalisation data for environmental profiling.

Keywords Australia · Characterisation · Inventory · Normalisation · Regional

1 Background, aim, and scope

Under the International Standard 14040 on the principles and framework of life-cycle assessment, normalisation is an optional step at the life-cycle impact assessment (LCIA) stage (ISO 2006). However, it is a very important part of the LCIA process because it provides environmental context by indicating the relative contribution that the product system under investigation makes in the various impact categories in comparison to a suitable reference scenario. In many instances, the adopted reference scenario is the total environmental impacts from a national (e.g. South Africa in Strauss et al. 2006), continental (e.g. Western Europe in Huijbregts et al. 2003) or even global population (e.g. Sleeswijk et al. 2008). The challenge for many studies however, is to provide the appropriate context by adopting a normalisation reference that is well matched to the product system's parent environment. Given that most of the currently published normalisation data is based on Western European conditions (Sleeswijk et al. 2008), this presents a particular challenge for other environments that do not share the same demographic and geographic characteristics.

Australia is the world's sixth largest country (land area 7,692,024 km^2) yet has a relatively small population of just over 20 million people (Australian Bureau of Statistics 2007; Geoscience Australia 2005). This represents an average population density of only 2.6 persons/km^2. However, Australia is actually a highly urbanised country, with 88.2% of the population living in major cities (>100,000 people). This is significantly higher than the world average of 48.6% and also higher than similarly industrialised regions such as Japan (66.0%), USA (80.8%) and Europe (71.9%; United Nations Secretariat 2007). Furthermore, Australia's urban population is mainly concentrated in the eight states and territory capital cities, leaving the remainder of the country relatively unpopulated. In the context of life-cycle assessment, and normalising environmental impacts against the profile of an 'average' Australian, this poses a unique problem. Far more than most other world regions, Australia requires a national emissions and resource consumption inventory that is regionally disaggregated. This study uses publicly available data on environmentally relevant emissions and non-renewable resource consumption to develop normalisation data for 60 regions across Australia from a production perspective. This study will assist the rapidly developing community of life-cycle assessment (LCA) practitioners in Australia to better characterise the relative significance of environmental impacts occurring in specific regions across the country.

2 Methods

2.1 Australian standard geographical classification

The Australian Bureau of Statistics has developed the Australian Standard Geographical Classification (ASGC) for the purpose of collecting and disseminating geographically classified statistics (Pink 2007). From the top down, Australia can be divided into States, then Statistical Divisions (SD), Sub-divisions (SSD) and Local Areas. The Statistical Local Areas are similar but not necessarily the same as jurisdictional Local Government Areas (LGA). For the purposes of data allocation in this study, the Statistical Division was adopted as the most appropriate regionalisation of the country, being one level of disaggregation below States. Table 1 (developed from Pink 2007) shows the 60 Statistical Divisions by State used in this study. Note the high proportion of the population in the eight State capital cities. Figure 1 shows the Australian states and territories and their capital cities.

Table 1 Statistical divisions by Australian Standard Geographical Classification (ASGC)

State	Statistical Division/Region Name	2005 Population	ASGC Statistical Division
New South Wales (NSW)	Sydney	4,254,894	105
	Hunter	610,526	110
	Illawarra	414,168	115
	Richmond-Tweed	225,886	120
	Mid-North Coast	295,144	125
	Northern	179,103	130
	North Western	118,885	135
	Central West	180,064	140
	South Eastern	202,757	145
	Murrumbidgee	153,871	150
	Murray	115,523	155
	Far West	23,428	160
Victoria (Vic)	Melbourne	3,634,233	205
	Barwon	269,752	210
	Western District	101,441	215
	Central Highlands	148,294	220
	Wimmera	50,884	225
	Mallee	92,087	230
	Loddon	175,406	235
	Goulburn	203,989	240
	Ovens-Murray	96,642	245
	East Gippsland	83,126	250
	Gippsland	166,492	255
Queensland (Qld)	Brisbane	1,777,490	305
	Gold Coast	501,450	307
	Sunshine Coast	282,645	309
	West Moreton	58,233	312
	Wide Bay-Burnett	256,993	315
	Darling Downs	222,478	320
	South West	26,996	325
	Fitzroy	189,838	330
	Central West	12,174	335
	Mackay	147,374	340
	Northern	205,628	345
	Far North	238,454	350
	North West	34,167	355
South Australia (SA)	Adelaide	1,129,269	405
	Outer Adelaide	123,924	410
	Yorke and Lower North	44,907	415
	Murray Lands	68,756	420
	South East	63,499	425
	Eyre	34,661	430
	Northern	77,017	435
Western Australia (WA)	Perth	1,477,815	505
	South West	219,812	510
	Lower Great Southern	53,738	515
	Upper Great Southern	17,760	520
	Midlands	52,372	525
	South Eastern	53,661	530
	Central	59,925	535
	Pilbara	39,282	540
	Kimberley	35,748	545
Tasmania (TAS)	Greater Hobart	210,328	605
	Southern	29,116	610
	Northern	137,936	615
	Mersey-Lyell	107,883	620
Northern Territory (NT)	Darwin	110,820	705
	Northern Territory	91,973	710
Australian Capital Territory (ACT)	Canberra	324,786	805
	Australian Capital Territory	375	810
Australia	60 statistical divisions	20,257,878	

2.2 National Pollutant Inventory

The National Pollutant Inventory (NPI) is a cooperative reporting programme implemented by the Australian State and Territory governments. Its aim is to provide information about substance emissions in Australia, from both point sources (i.e. specific facilities) as well as diffuse sources (e.g. agriculture, cigarettes, motor vehicles, dust, etc.). The NPI reports emission estimates for 93 toxic substances, together with the source and location of these emissions. Table 2 shows the substances tracked by the NPI (2008a). The NPI dataset for 2005/2006 includes 46,775 point source emissions, from 3,386 facilities in 529 LGAs across Australia. It also includes diffuse emissions in 24 specific air-shed surveys and 22 specific water catchment surveys, including Australia's largest catchment, the Murray–Darling Basin which covers parts of five Australian states and territories (NPI 2008a, b, c). The coverage of air-shed and water catchment surveys is not exhaustive for the country. Therefore, diffuse emissions are likely to be significantly underestimated in the NPI.

The 529 LGAs recorded in the 2005/2006 NPI were classified into 60 SDs, according to the ASGC structure. The 46,775 point source emissions were then classified into SD, using a simple lookup function in MS Excel on the 'Spatial LGA' recorded for each of the 3,386 facilities in the NPI. Diffuse emissions from the air-shed and water catchment surveys were similarly classified into SDs.

Fig. 1 Australian states and territories

Table 2 Pollutants tracked by the Australian national pollutant inventory (2005/2006)

Substance			
Acetaldehyde	Chloroform (trichloromethane)	Glutaraldehyde	Phosphoric acid
Acetic acid (ethanoic acid)	Chlorophenols (di, tri, tetra)	n-Hexane	Polychlorinated biphenyls
Acetone	Chromium (III) compounds	Hydrochloric acid	Polychlorinated dioxins and furans
Acetonitrile	Chromium (VI) compounds	Hydrogen sulfide	Polycyclic aromatic hydrocarbons
Acrolein	Cobalt and compounds	Lead and compounds	Selenium and compounds
Acrylamide	Copper and compounds	Magnesium oxide fume	Styrene (ethenylbenzene)
Acrylic acid	Cumene (1-methyl ethylbenzene)	Manganese and compounds	Sulphur dioxide
Acrylonitrile (2-propenenitrile)	Cyanide (inorganic) compounds	Mercury and compounds	Sulphuric acid
Ammonia (total)	Cyclohexane	Methanol	1,1,1,2-Tetrachloroethane
Aniline (benzenamine)	1,2-Dibromoethane	2-Methoxyethanol	Tetrachloroethylene
Antimony and compounds	Dibutyl phthalate	2-Methoxyethanol acetate	Toluene (methylbenzene)
Arsenic and compounds	1,2-Dichloroethane	Methyl ethyl ketone	Toluene-2,4-diisocyanate
Benzene	Dichloromethane	Methyl isobutyl ketone	Total nitrogen
Benzene hexachloro- (HCB)	Ethanol	Methyl methacrylate	Total phosphorus
Beryllium and compounds	2-Ethoxyethanol	Methylenebis (phenylisocyanate)	Total volatile organic compounds
Biphenyl (1,1-biphenyl)	2-Ethoxyethanol acetate	Nickel and compounds	1,1,2-Trichloroethane
Boron and compounds	Ethyl acetate	Nickel carbonyl	Trichloroethylene
1,3-Butadiene (vinyl ethylene)	Ethyl butyl ketone	Nickel subsulfide	Vinyl chloride monomer
Cadmium and compounds	Ethylbenzene	Nitric acid	Zinc and compounds
Carbon disulfide	Ethylene glycol (1,2-ethanediol)	Organo-tin compounds	Xylenes (individual or mixed isomers)
Carbon monoxide	Ethylene oxide	Oxides of nitrogen	
Chlorine	Di-(2-Ethylhexyl) phthalate	Particulate matter 2.5 μm	4,4′-Methylene-bis (2-chloroaniline)
Chlorine dioxide	Fluoride compounds	Particulate matter 10.0 μm	
Chloroethane (ethyl chloride)	Formaldehyde (methyl aldehyde)	Phenol	

Emissions in the Murray–Darling Basin were apportioned to Statistical Divisions based on the estimated land area of each relevant SD within the catchment (Crabb 1997). Once all the NPI data were classified into SDs, they were compiled by substance and Statistical Division using summation pivot tables in MS Excel.

With only 93 substances gazetted, the NPI does not track all environmentally relevant substances. By comparison, the IMPACT 2002+ LCIA methodology (Jolliet et al. 2003) tracks over 430 substances in its aquatic and terrestrial ecotoxicity categories. Even many substances with very high toxicity characterisation factors, such as the flame retardant hexabromobenzene, are not captured in the NPI. More significantly, data on pesticide use in Australia are very limited and difficult to interpret (AATSE 2002, p. 4) and, hence, are not included in this study. Some basic estimates of pesticide use have been made in similar studies (e.g. Lundie et al. 2007); however, the data are by no means comprehensive, nor are they disaggregated by State or region and, thus, cannot be easily fitted to the structure of the national inventory in this study. From both inventory and regulatory perspectives, this omission warrants further investigation in Australia.

Table 3 Greenhouse gases tracked by Australian Greenhouse Emissions Information System (AGEIS) and non-renewable energy resources and minerals tracked by Australian Bureau of Agricultural and Resource Economics (ABARE)

AGEIS Kyoto protocol greenhouse gases	ABARE non-renewable energy resources	ABARE minerals	
Carbon dioxide (CO_2)	Black coal	Bauxite	Phosphate rock
Methane (CH_4)	Brown coal	Copper	Silver
Nitrous oxide (N_2O)	Crude oil	Gold	Tin
Pentafluoroethane (HFC-125)	Naturally occurring LPG	Iron ore	Titanium dioxide
1,1,1,2-tetrafluoroethane (HFC-134a)	Natural gas	Lead	Zinc
1,1,1-trifluoroethane (HFC-143a)	Ethane	Manganese	Zircon concentrate
Tetrafluoroethane (CFC-14)	Uranium	Nickel	
Hexafluoroethane (HFC-116)			
Sulphur hexafluoride (SF6)			

2.3 Australia greenhouse emissions information system

The Australian Greenhouse Emissions Information System (AGEIS) provides comprehensive data on Australia's greenhouse gas emissions and is reported by State, by industry and by greenhouse gas (AGEIS 2007). Table 3 shows the significant greenhouse gases tracked by AGEIS under the Kyoto Protocol. These AGEIS data from 2005, reported by State, are used as the basis of the greenhouse gas emissions inventory in this study. Allocation of emissions to each SD within each State is on the basis of population.

2.4 Australian energy and mineral statistics

The Australian Bureau of Agricultural and Resource Economics (ABARE) undertakes statistical research and economic analysis of Australia's agricultural, fishing, forestry, energy and minerals industries. As part of these duties, ABARE publishes National quarterly mineral production statistics for a range of important minerals. It also publishes annual energy production statistics, disaggregated by State (ABARE 2006, 2007). Table 3 shows the resources which are tracked in these ABARE publications and are used as the basis of the 2005/2006 non-renewable energy and mineral production inventories in this study.

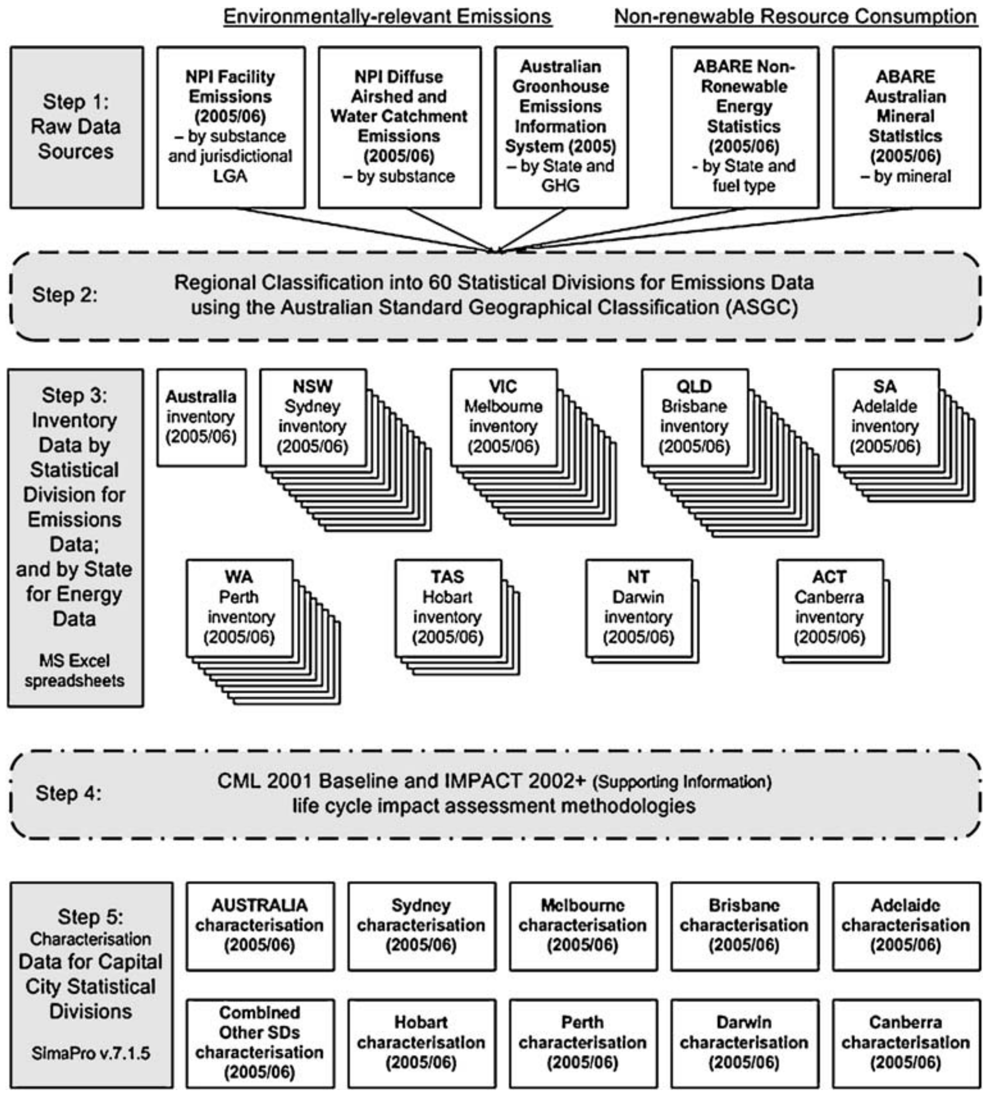
In the absence of comprehensive data on the specific locations of all production facilities, it is not possible to fairly allocate the inventories and impacts of minerals and non-renewable energy production (i.e. local consumption plus exports but excluding imports) to each SD. Hence, these data are presented by State for non-renewable energy production and by the whole country for mineral production data.

2.5 Data collation and analysis

The emissions and resources production data from these three data sources have been analysed using the methodology illustrated in Fig. 2 to construct ASGC-regionalised emissions and resources production inventory for 2005/2006. The full inventory datasets (NPI, AGEIS, ABARE), disaggregated by SD, are available in MS Excel spreadsheets in the Supporting Information. If required, these data could be used by any LCA practitioner to construct characterisation/normalisation data by impact category for any region or State of the country. This can be done using any of the widely available LCIA methods (e.g. CML, Eco-Indicator 99, IMPACT 2002+, TRACI, etc.) implemented in spreadsheet form or in commercially available LCA software packages (e.g. SimaPro, Gabi, etc.).

Australia's state and territory capital cities represent 67% of the national population (see Table 1). This study uses SimaPro (v.7.1.5) to apply the CML 2001 baseline LCIA method (Guinee 2002) to the inventory data of the eight capital cities, as well as the National inventory data and the inventory data of the combined remaining SDs (see Fig. 2). The inventory record entered into SimaPro (v.7.1.5) for each capital city consists of 20 resources

Fig. 2 Methodology flowchart



production line items, 168 air emission line items, 78 water emission line items and 70 soil emission line items. All emissions to the 'air' compartment are assumed to be in 'high population' areas. All emissions to the 'water' compartment are assumed to be to 'rivers'. All emissions to the 'soil' compartment are assumed to be in 'industrial' areas. Similar distinctions could be made in other software packages. Characterisation results using IMPACT 2002+ (Jolliet et al. 2003) are also available in the Supporting Information.

It should be noted that one of the weaknesses of this study is the application of European-based impact assessment models to Australian inventory data. As demonstrated by Lundie et al. (2007), toxicity characterisation factors for Australia can be significantly different to those estimated under European climatic and demographic conditions. However, in the absence of a comprehensive Australian LCIA method, the CML 2001 baseline and IMPACT 2002+ methods are adopted as best practice.

3 Results

The characterisation results for Australia's major cities, according to the CML 2001 baseline categories, are shown in Table 4 and Figs. 3 and 4. Following the ratification of the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987, Australia has largely phased out the use of ozone depleting substances (DEWHA 2008), so none of these are recorded in the Australian inventory; hence, this LCIA category is not shown.

The default CML 2001 baseline method in SimaPro (v.7.1.5) recorded 66 inventory items as 'unassessed'—24 substances emitted to air, 21 substances emitted to water and 21 substances emitted to soil. These are items from the inventory that have no corresponding characterisation factors in any of the impact categories of the LCIA method. See the Supporting Information for further details.

Table 4 Characterisation results for Australia and capital cities by CML 2001 baseline impact assessment method

Impact category	Unit	Sydney	Melbourne	Brisbane	Perth	Adelaide
Abiotic depletion (energy by State)	kg Antimony-eq/year	1.657E+09	6.810E+08	2.407E+09	8.613E+08	1.372E+08
Acidification	kg SO_2-eq/year	1.156E+08	1.399E+08	8.998E+07	5.086E+07	2.273E+07
Eutrophication	kg PO_4-eq/year	4.267E+07	3.345E+07	2.654E+07	1.346E+07	8.045E+06
Global Warming (GWP100)	kg CO_2-eq/year	1.027E+11	9.012E+10	7.395E+10	4.999E+10	2.114E+10
Human Toxicity	kg 1,4dichlorobenzene-eq/year	8.311E+10	1.183E+11	2.323E+10	8.313E+10	3.637E+10
Freshwater Aquatic Ecotoxicity	kg 1,4DB-eq/year	6.876E+07	8.994E+07	1.507E+07	3.754E+07	9.820E+07
Marine Aquatic Ecotoxicity	kg 1,4DB-eq/year	3.737E+11	3.657E+11	1.713E+11	1.021E+11	1.052E+11
Terrestrial Ecotoxicity	kg 1,4DB-eq/year	2.022E+07	5.220E+07	1.322E+07	1.536E+07	9.728E+06
Photochemical Oxidation	kg C_2H_4-eq/year	4.820E+07	3.943E+07	3.510E+07	1.680E+07	1.057E+07
Impact Category	Unit	Canberra	Hobart	Darwin	Other SDs	Australia
Abiotic Depletion (Minerals)	kg Sb-eq/year					8.251E+07
Abiotic Depletion (Energy by State)	kg Sb-eq/year	inc. in NSW	7.772E+06	4.340E+07		5.794E+09
Acidification	kg SO_2-eq/year	5.450E+06	6.032E+06	6.211E+06	2.116E+09	2.553E+09
Eutrophication	kg PO_4-eq/year	2.094E+06	3.112E+06	2.299E+06	2.924E+08	4.241E+08
Global Warming (GWP100)	kg CO_2-eq/year	1.222E+09	4.955E+09	7.726E+09	2.253E+11	5.771E+11
Human Toxicity	kg 1,4DB-eq/year	1.515E+10	4.107E+10	1.519E+09	3.437E+11	7.456E+11
Freshwater Aquatic Ecotoxicity	kg 1,4DB-eq/year	7.683E+06	1.986E+07	1.434E+07	1.585E+09	1.937E+09
Marine Aquatic Ecotoxicity	kg 1,4DB-eq/year	3.950E+10	6.477E+10	8.097E+09	1.144E+13	1.267E+13
Terrestrial Ecotoxicity	kg 1,4DB-eq/year	2.729E+06	6.792E+06	3.047E+07	2.205E+09	2.356E+09
Photochemical Oxidation	kg C_2H_4-eq/year	2.895E+06	4.176E+06	3.405E+06	1.649E+08	3.255E+08

4 Discussion

4.1 Comparison of per capita characterisation profiles for capital cities

Following is a brief discussion on the per capita CML 2001 baseline characterisation profile illustrated in Fig. 4. This analysis examines the major contributing inventory items to the regions to explain why some cities carry higher environmental burdens per capita than others.

In terms of abiotic depletion, the regional profiles across cities are relatively similar. Darwin, Perth, Brisbane and Melbourne are slightly higher than the other cities. In the case of Darwin and Perth, this is due principally to the high use of natural gas for meeting energy demands. In Brisbane and Melbourne, it is due

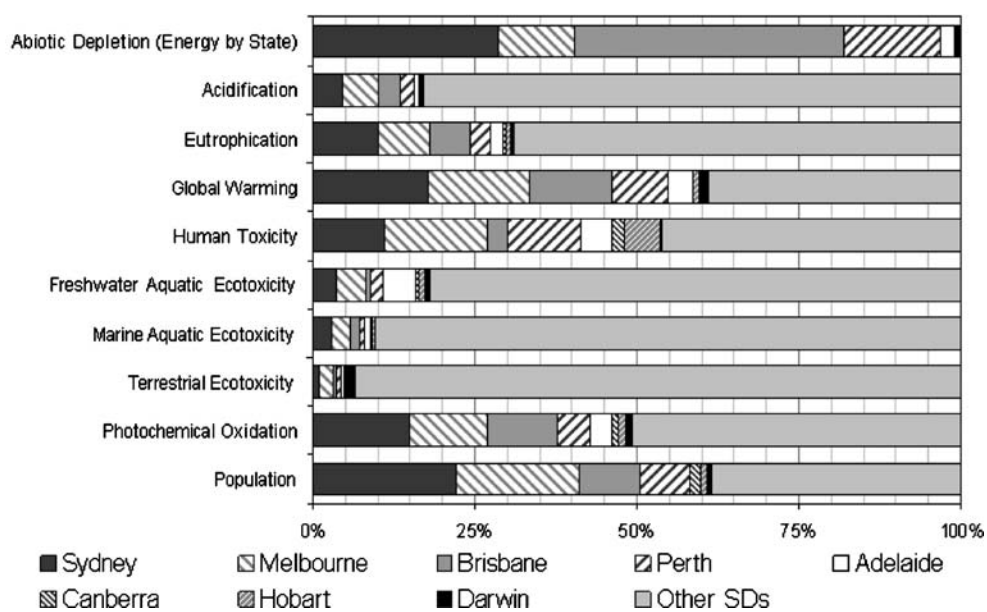


Fig. 3 Percentage contribution to characterisation results for Australia by capital cities (CML 2001 baseline LCIA method)

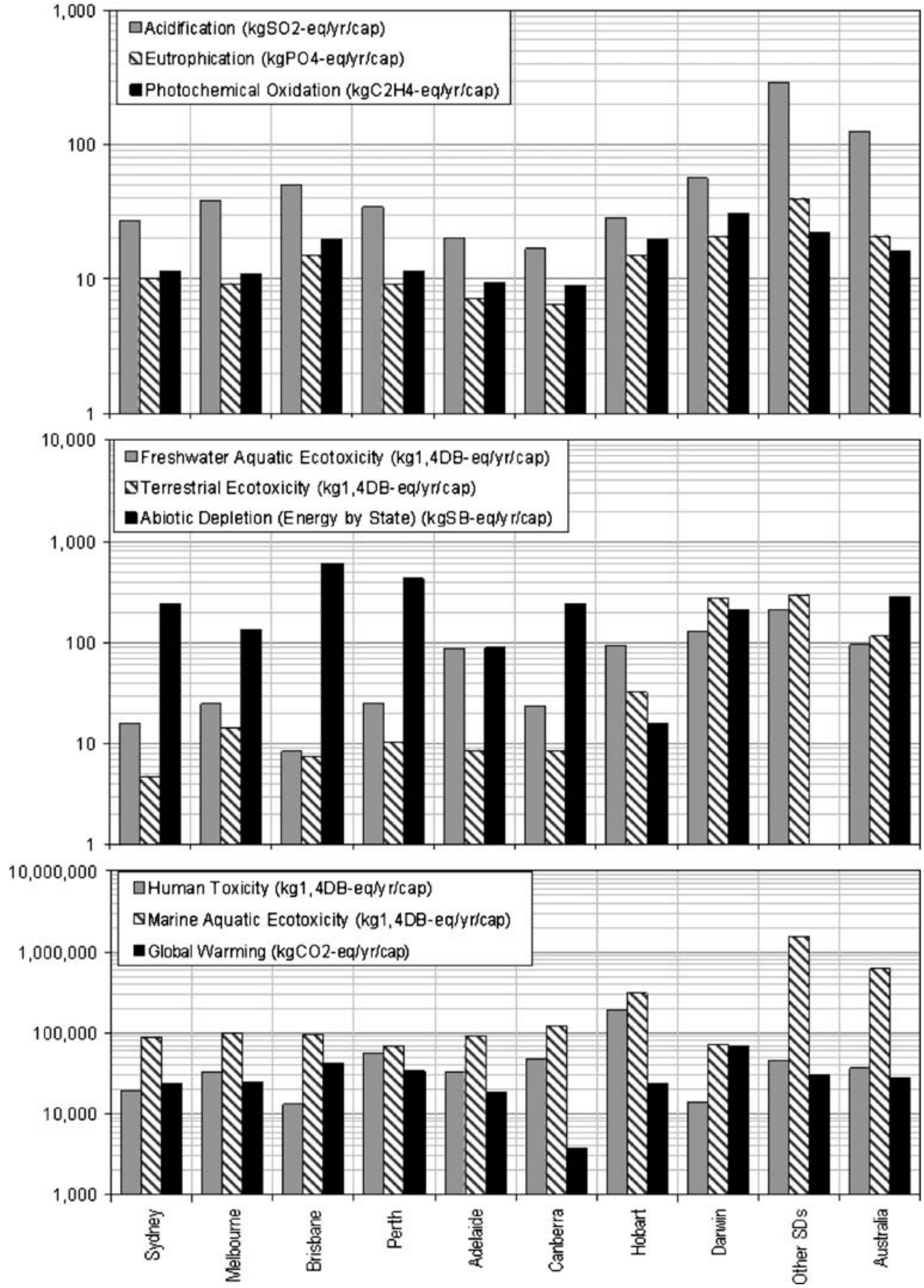


Fig. 4 Characterisation results per capita for Australia by capital cities (CML 2001 baseline LCIA method)

to coal consumption and particularly brown coal consumption for Melbourne.

The acidification and eutrophication categories are noteworthy because of the substantially higher per capita emissions from the combined ‘Other Statistical Divisions’ (i.e. the other 52 SDs outside of the capital cities). In large part, these impacts are due to nitrogen oxides and sulphur oxides emissions from coal-fired power stations, mining and mineral processing operations. In Australia, mineral processing and the generation of electricity is mostly undertaken in regions outside the main urban areas. The products of these operations are however largely consumed in the cities. Therefore, whilst the environmentally relevant emissions from these operations occur in non-urban areas, they could be considered part of the true environmental footprint of the urban population.

The global warming category highlights an unusual contributing factor. Whilst carbon dioxide from fossil-fuelled electricity generation is the most dominant greenhouse gas in Australia (AGEIS 2007), the per capita

greenhouse gas emissions from Darwin are also heavily affected by methane and nitrous oxide emissions from the 'prescribed burning of savannahs'. Similarly, this land management practice also creates significant carbon monoxide emissions, making Darwin the highest per capita emitter on photochemical oxidation potential (i.e. smog).

The ecotoxicity categories (fresh water, marine and terrestrial) are all similarly influenced by emissions of heavy metals (e.g. nickel, copper, chromium, arsenic, mercury) from mining and minerals processing operations. These facilities are almost exclusively located in non-urban areas, hence the predominance of the 'Other Statistical Divisions' in these LCIA categories. The fresh water ecotoxicity impacts of Darwin are also influenced by the reporting of six heavy metal compounds in its Darwin Harbour water catchment survey (i.e. estimated diffuse emissions). These heavy metals are not estimated in any other water catchment survey in the NPI and, thus, represent a major weakness in the reporting methodology. The terrestrial ecotoxicity results for Darwin are also significantly higher than the other capital cities. This can be traced to a single facility emission in the NPI: 500 kg of mercury compounds disposed to Darwin City Council's Leanyer Waste Disposal Site, representing over 80% of the nation's estimated mercury emissions for 2005/2006.

In the human toxicity category, Hobart is the capital city with the most substantial impacts per capita. Analysis of the contributing NPI data shows this to be mainly due to diffuse polycyclic aromatic hydrocarbon (PAH) emissions from solid fuel burning. Hobart is Australia's most southerly capital with the coldest climate. Heating requirements are at least partly met by solid fuel burning and, hence, the higher per capita emissions of PAHs for this city. Similarly, Brisbane and Darwin (Australia's most northerly and warmest capital cities) have the lowest emissions in this regard.

Comparison of Australia's average per capita CML 2001 baseline characterisation results (2005/2006) with the Netherlands (1997/1998), Western Europe (1995) and the World (1995) in Table 5 shows them to be broadly similar in magnitude (Huijbregts et al. 2003).

4.2 Implications of the production perspective

The inventory data compiled in this study reflects the emissions and resource extractions associated with production. For many agricultural, technological and service-based products and natural resources (i.e. black coal, natural gas, uranium and all of the mineral resources listed in Table 3), Australia is a net exporter (refer to Supporting Information). Therefore, a significant part of the characterisation data presented here for Australia represents products that will be consumed in other parts of the world. Similarly, at a regional level, there will be many inventory items produced in one area, yet consumed in another. In this way, the impacts associated with consumption (particularly in densely populated but largely industry-free cities) are dissipated into other production centres.

It is important that users of the characterisation data presented in this study for normalisation purposes are mindful of this distinction between production and consumption perspectives and that it matches the scale and construction of the product system under investigation.

5 Conclusions

This study has drawn on extensive publicly available data to construct a regionally distributed profile of Australia's environmentally relevant emissions and non-renewable resource production. It, thus, provides the first set of comprehensive inventory and characterisation data for Australia, disaggregated at a regional level. Despite

Table 5 Comparison of per capita characterisation results for Australia against the Netherlands, Western Europe and the World by CML 2001 baseline impact assessment method

Impact Category	Unit	Australia 2005/06	The Netherlands 1997/98	Western Europe 1995	World 1995
Abiotic Depletion	kg Sb-eq/year/cap	2.893E+02	1.06E+02	3.95E+01	2.81E+01
Acidification	kg SO_2-eq/year/cap	1.257E+02	3.31E+01	5.26E+01	5.61E+01
Eutrophication	kg PO_4-eq/year/cap	2.087E+01	8.75E+00	1.13E+01	1.07E+01
Global Warming (GWP100)	kg CO_2-eq/year/cap	2.841E+04	1.56E+04	1.26E+04	7.19E+03
Human Toxicity	kg 1,4DB-eq/year/cap	3.670E+04	1.19E+04	2.00E+04	1.00E+04
Fresh Water Aquatic Ecotoxicity	kg 1,4DB-eq/year/cap	9.532E+01	4.69E+02	1.33E+03	3.51E+02
Marine Aquatic Ecotoxicity	kg 1,4DB-eq/year/cap	6.235E+05	2.69E+05	2.89E+05	8.95E+04
Terrestrial Ecotoxicity	kg 1,4DB-eq/year/cap	1.160E+02	6.00E+01	1.24E+02	4.74E+01
Photochemical Oxidation	kg C_2H_4-eq/year/cap	1.602E+01	1.13E+01	2.16E+01	1.68E+01

Australia's unique spatial demography, it is now possible to properly characterise the relative significance of environmental impacts occurring in any specific region across the country.

The inventory data for Australia's eight states and territory capitals is assessed using the well-known CML 2001 baseline life-cycle impact assessment method, as it is implemented in SimaPro v.7.5.1. These results, along with a combined national characterisation profile, are presented in this paper and compared against other published profiles for the Netherlands, Western Europe and the world. Analysis of the CML 2001 baseline characterisation results, on a per capita basis, show substantial differences between the major cities of the country. Interestingly, many significant impacts occur outside of the capital cities but are linked to facilities providing the majority of their services and products to these urban centres (e.g. power stations, minerals processing). Similarly, as a net exporter of many products, the Australian inventory and characterisation data presented here also represents a substantial fraction of the consumption impacts in other parts of the world.

6 Recommendations and perspectives

Australia's unique concentration of urban populations demonstrates the importance of regionally specific environmental assessments. Whilst the data presented in this study will be of most use to Australian LCA practitioners, they are also demonstrative of the broader global distribution of environmental impacts between urban and non-urban areas. The disconnection of environmental impacts between the place of production and the place of consumption is highlighted by this study and should be considered in any studies using these normalisation data for environmental profiling.

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